

Research Article

# A Speed Based Congestion Study of a Road Section Connecting Fulbarigate-Dakbangla, Khulna

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## Abstract

Congestion, a problem that is not new for a third world country like Bangladesh. Like the other megacities of Bangladesh, Khulna is gradually experiencing this phenomenon in an acute manner. Khulna-Jessore highway that runs through the city and gives it a linear form works as the backbone of the traffic skeleton of Khulna city. This study focuses on developing a speed based model for predicting congestion scenario of Khulna city. Fulbarigate to Dakbangla midblock is chosen as the study corridor. The whole study corridor (10.73km) is divided into two equal halves and travelled 10 times with the stream and against the stream to generate 20 data set. Speedometer GPS survey along with moving observed method is used to collect necessary data. A latitude longitude based speed profile is found at each travel based on which travel speed index (TSI) is calculated and a multiple linear regression (MLR) model for predicting congestion is developed. Independent variables are selected based on the possibility of affecting congestion of the road section. The MLR model is found as  $TSI = 0.0167083 + 0.0001826 * Volume (PCU/hr.) + 0.0019625 * Speed Drop Factor$ , with 8.86 % error. Congestion is found severe at Doulatpur Bazar and Shibbari to Dakbangla circle within the study corridor. Due to illegal parking spot, road capacity is not utilizing properly. As a result in peak hour, speed drops more than average peak hour speed and congestion occurs.

**Keywords:** Traffic Congestion, Moving Observer Method, MLR Model, Speedometer GPS, Speed profile

## 1. Introduction

Congestion, a term that is making urban life slower, generates such a trouble that is now seeking attention in almost all developing as well as developed countries. Since the end of the Second World War, high demand for mobility increases due to rapid urbanization and economic growth in third world cities (Chakrabarty, *et al*, 2015). In a third world country like Bangladesh, traffic congestion is faced by almost all the mega cities like Dhaka, Chittagong etc. (Shamsher, *et al*, 2013). The congestion scenario of mega cities is enough to predict the alarming situation for the cities under major infrastructural development. Khulna, the third largest city of Bangladesh, in such case is the next to recur the same incidence (Moniruzzaman, 2013). Major development projects e.g. Padma Bridge, Khulna-Mongla Rail Road project have been taken to link Khulna with the other parts of the country in order to accelerate the economic growth of Bangladesh (Bangladesh Bridge Authority, 2017). Again, traffic information is now required by vehicle drivers, traffic police, and road construction planners. Drivers want to know the status of the road to avoid traffic congestion. The traffic police demand information on intersections

to reduce traffic jam through improvement of signal system. Transport planners use traffic information as one of the factors for choosing locations where road expansion is required. Thus predicting the present scenario of congestion in Khulna city is necessary to identify the congested nodes throughout the city.

The objective of the study is to develop a prediction model of traffic congestion for heterogeneous traffic. To fulfill the objective, two research questions are formulated. First one is to identify the present scenario of traffic congestion in Khulna City and second one is to identify the factors affecting traffic congestion. This study generates a prediction model regarding the traffic congestion scenario of Khulna city. Main reasons behind the congestion can be sorted out through this speed based congestion study. Finally, this study would enable policy makers to take decisions regarding Khulna city transportation by ensuring efficient resource allocation before the congestion scenario gets even worse.

## 2. Literature Review

### 2.1 Traffic Congestion

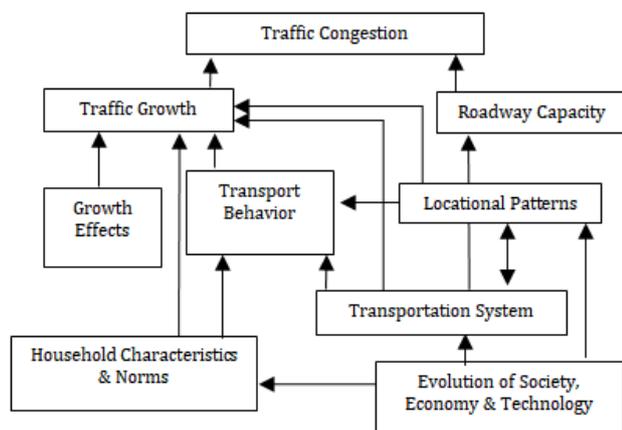
Congestion can be of two main types- Recurrent (too many vehicles using the same road at the same time), Non-recurrent (disabled vehicles, accidents, work

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zones such as street cleaning) congestion (Chakrabartty, et al, 2015). Remiet al. (2009) defined traffic congestion as a condition that occurs while road use increases characterized by slower speeds, longer trip times, increased number of vehicles. Congestion is a condition, arises as more people wish to travel at a given time than the transportation system can accommodate, can be represented as a simple case of demand exceeding supply (Miller, et al., 1994). It also takes place when travel demand exceeds the existing road system capacity (Rosenbloom, 1978).

### 2.2 Generation of Traffic Congestion

Traffic congestion occurs on fixed road capacity exceeding 90% of the capacity. As a result, level of service (LOS), which is measured by speed or delay, deteriorates to unacceptable level. The growth of traffic is affected by four major factors : (1) the natural growth of population, (2) locational patterns (i.e. spatial distribution of residence, work, shopping and places of recreation), (3) transportation characteristics and policies, and (4) transport behavior of individuals and household manifested in their mode choice, departure time, route choice and so on (Papacostas, et al., 2001).



Source (Papacostas, et al., 2001)

**Fig.1** Causes of generating congestion

### 2.3 Congestion Measuring Parameters

Levinson and Lomax (1996) developed a congestion index which measures the differences in actual versus desired travel time. Congestion index (CI) can be represented as the ratio of mean travel time to free-flow travel time (McDonald, et al.). Lomax et al., (1997) defined corridor mobility index (CMI) as a measure of person-carrying capacity of corridors. Travel rate index (TRI) measures amount of additional time required to make a trip because of congestion (Das, et al, 2016).

Buffer time index measures extra percentage of travel time that a traveler should allow when making a trip in order to be on time 95% of the time. Traveler adds this amount of time onto a trip when planning trips (Kansas and Missouri Departments of Transportation, 2011).

Lindley denoted a situation as congestion while volume to capacity ratio exceeds 0.77 (Lindley, 1987). Roadway congestion index (RCI), developed by Shrank and Lomax (2005), is a measure of daily VMT (Vehicle Miles Travelled) per lane-mile of freeways and principal arterial streets. It is an empirically derived formula to quantify the relative congestion levels across metropolitan areas (Rao and Rao, 2012). Lane-mile duration index (LMDI), by Cottrell (1991), calculates average annual daily traffic volume per hourly capacity (Rao and Rao, 2012).

### 2.4 Congestion Measuring through TCS

In the year of 2016 Das, et al, established an MLR model based on traffic congestion score (TCS) derived from speed against distance curve. A two km study corridor was selected. An average speed of peak time was considered as the standard speed in peak hour. V-box was used to collect speed data profile based on distance (m). In the speed vs. distance curve the area between the standard speed and the speed observed below this is termed as congestion patch area. Volume/km, vehicle composition, friction spot and speed drop factor were considered as independent variables for this model (Das, et al, 2016).

### 2.5 Congestion Measuring through TTI

In 2016, Henry and Koshy developed an MLR model to predict traffic congestion using travel time index (TTI) as dependent variable. Number of pedestrians crossing the traffic stream, Volume of crossing, merging and diverging traffic, sum of average dwell time of buses was considered as independent variables here. For this study, a 1.4 km state highway- 1 section (between Kumaranalloor and Gandhi Nagar, Kottayam of Kerala state, India) was taken. Moving car method was conducted to derive actual travel time of car both in morning and evening peak periods. This study area had heterogeneous traffic though number of car was the most comparing to other vehicles. From the analysis of hourly variation of congestion it was found that vehicles take 81% to 133% longer travel time in traversing the section (Henry and Koshy, 2016).

### 2.6 Congestion Prediction Model using R Programming

R is a language and environment for statistical computing and graphics that provides a wide variety of statistical linear and nonlinear modeling. Lee, et al, performed an MLR analysis for predicting the changes in traffic congestion based on weather data in 2015. The data used in the analysis included weather data in the residential area, the destination as well as traffic congestion data in the destination. Altogether 48 independent variables were used in the regression analysis, including temperature, humidity, and cloud, rainfall, and wind velocity. Six days of week were considered as six dummy variables to fit the MLR model. Regression models were not created for each

day of the week. Instead, a single model for the entire week was created. To process weather and traffic data sets Hadoop software was used. Dependent variable traffic congestion score (TCS) was calculated using Hadoop software considering speed profile of link roads. Time required to travel 1 km road section was calculated by the aggregation method here. Then R programming was used to remove variable and justify multiple linear regression model. The final prediction model presents accuracy level more than 75.5% with the actual result.

2.7 MLR Modeling through GPS Data

Satyakumar, et al, in 2012 formulated an MLR model using GPS data. Both peak and off-peak hour congestion were considered in this model. Separate models were developed for 2 wheelers, 3 wheelers, cars and public transit vehicles for morning and evening peak hours. Kesavadasapuram-Pattom stretch in India was considered as study area. GIS software was used as a database for storing and manipulating transportation data collected through GPS. Variation of congestion indices (LOS, CI, travel rate ratio, v/c ratio, and delay rate index) were represented using GIS software. Here, speed was considered as dependent variable. Finally, regression model through SPSS software derived the equation with an R-squared value of 0.852:  $Speed (public\ transits) = 28.74 - 0.004\ TW - 0.059\ A + 0.004\ C - 0.096\ B - 0.644\ G + 0.014\ PTW - 0.238\ PA - 0.014\ PC - 0.258\ PG$ ; Where, A = Number of auto, PA = Number of autos parked, B = Number of bus, PG = Number of goods vehicle parked, C = Number of cars, PC = Number of parked cars, TW = Number of two wheelers, G = Number of goods vehicle, PTW = Number of parked two wheelers.

3. Study Area

Khulna is the 3<sup>rd</sup> largest city after Dhaka and Chittagong having a population of 759877 (Ministry of Planning, 2015). Khulna is located in South-West part of Bangladesh at 22°49'0"N 89°33'0"E, on the banks of the Rupsha and Bhairab River. The city has a strong industrial base on shrimp cultivation, which is the second biggest foreign exchange earner in Bangladesh (Ahmed, 2011). Major industries (Jute mills, Saw Mills etc.), trade and commerce are developed beside Khulna-Jessore highway. For this study, a road section from Fulbarigate to Dakbangla circle was considered as this is the highly congested road section in Khulna City Corporation area. Total length of the study road section was 10.73 km. As a whole 10 types of modes are available throughout the road sections. Here public transport vehicles are higher in number than private vehicles (i.e. car).

Table 1 Modes available in the study route

Mode of Transport	Mode of Transport
Bus	Rickshaw
Truck	Van
Auto	Motor cycle
CNG	Cycle
Mahindra	Car

Source Field Survey, 2018

Seven road sections have been considered to conduct volume survey. Major intersections are considered to divide the whole study corridor into seven sections. Sections which have been considered are mentioned below in Table 2.

Major intersections throughout the study area are named by Fulbarigate, Doulatpur, Notun Rasta Circle, Shibbari Circle, Powerhouse Circle, Ferryghat and Dakbangla Circle. Physical feature survey has also been conducted throughout the study road sections.

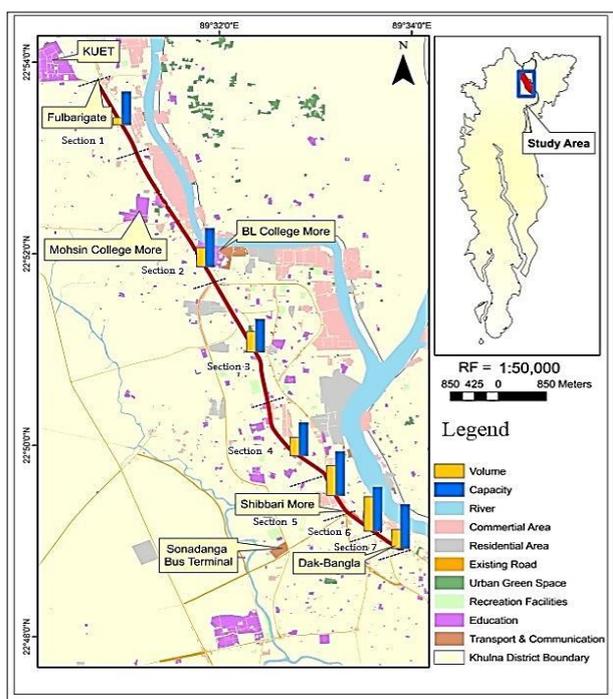


Fig. 2 Map of the Study Corridor; Source Author, 2018

Table 2 Physical features throughout the road section

Section	Location	Effective Road Width	Lane Number	Illegal Parking Spot	Speed Breaker Number
1	Fulbarigate to Notun Rasta	35'	1	2	2
2	Notun Rasta to Boyra	44'	2	4	3
3	Boyra to Joragate	40'	1	2	1
4	Joragate to Shibbari	35'	1	4	4
5	Shibbari to Powerhouse	35'	1	1	2
6	Powerhouse to Ferryghat	35'	1	0	3
7	Ferryghat to Dakbangla	44'	2	7	0

Source Field Survey, 2018

Overall volume to capacity ratio shows how smoothly the vehicles can operate on the facility. This ratio remains highest (0.784) in case of Powerhouse to Ferryghat Circle which is considered to be the most congested section within the study corridor (Table 3).

**Table 3** Section specific V/C ratio

Section	Volume (PCU/hr)	Capacity (PCU/hr)	V/C ratio
1	910.6	4200	0.21681
2	1979	5600	0.353393
3	2643.3	4200	0.629357
4	2343.6	4200	0.55800
5	3819.3	5600	0.682018
6	4391.7	5600	0.784232
7	2424.9	5600	0.433018

Source Field Survey, 2018

**4. Methodology**

To identify congested nodes throughout the study route, *Speedometer GPS* app along with moving observer method has been used. Here *Speedometer GPS* app is used to identify location specific congestion. Congestion patch area has been identified where speed falls below the average speed of each peak hour travel. The record of this app has been extracted through Google Earth. At every two minutes interval a ground control point (GCP) has been located in Google Earth through the app. Then distance between two consecutive points has been measured. Thus latitude longitude based journey speed (in KPH) has been extracted. Value of the dependent variable travel speed index (TSI) has been calculated using the formula (Das, et al, 2016).

$$TSI = \frac{\text{Congestion patch area}}{\text{Maximum congestion patch area}} \quad (1)$$

Congested patch area is the area (P1, P2, P3) marked by the average speed line of the study corridor covering the speed profile observed below the average speed line and maximum congestion patch area (A1, A2, A3) is marked below the speed profile line for the congestion stretch up to zero reference speed i.e. when the vehicle is in stopped condition the congestion is maximum (Fig. 4). Moving observer method has also been used to identify the value of 8 independent variables (Table 4). The study corridor is divided into two equal halves (5.36 km each) and this survey procedure has been repeated 10 times in peak hour with the stream and against the stream to generate 20 data sets for the MLR model. A test car has been used to collect necessary data with the app. TSI is calculated each time and the changes in the value of independent variables are recorded.

**Table 4** List of independent variables for MLR model

Volume (PCU/hr.)	Speed drop factor
% of 2 wheelers (i.e. cycle, bike)	% of 4 wheelers (i.e. Bus, car)
% of 3 wheelers (i.e. Mahindra, auto)	% of commercial vehicles (i.e. truck, van)
Friction Spot	Dwell time of test vehicle

Source Author, 2018

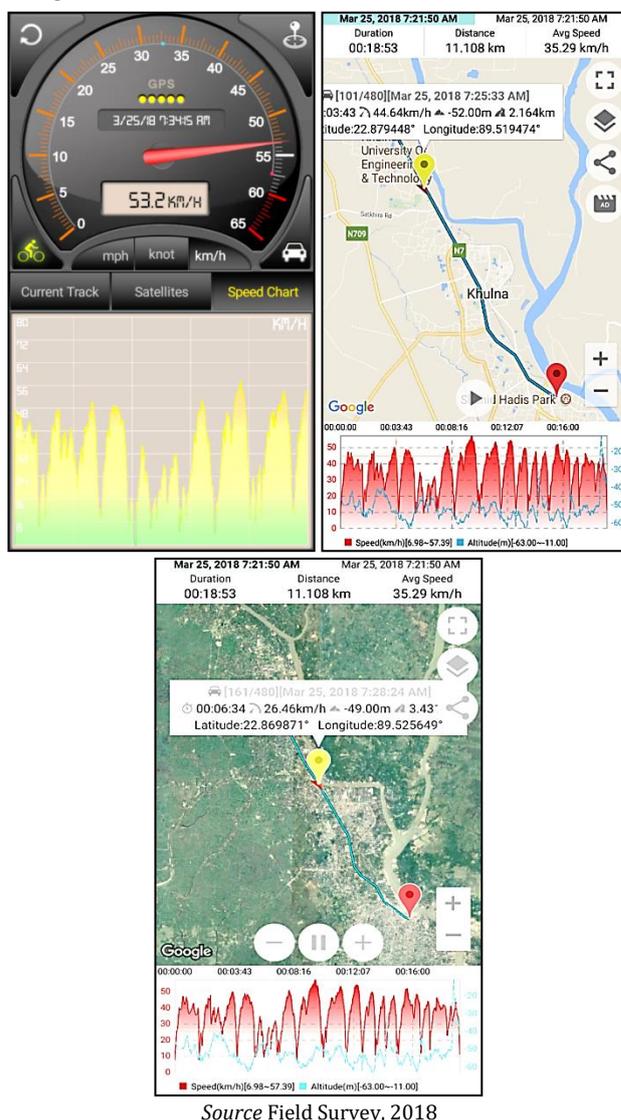
Statistical programming language R has been used to generate a multiple linear regression (MLR) model including 8 independent variables which possibly affect the dependent variable TSI (Proxy variable for congestion). The variables that are not significant have been removed by backward test, multicollinearity test and significance test as mentioned in Fig 5.

**4.1 Congested Node Identification**

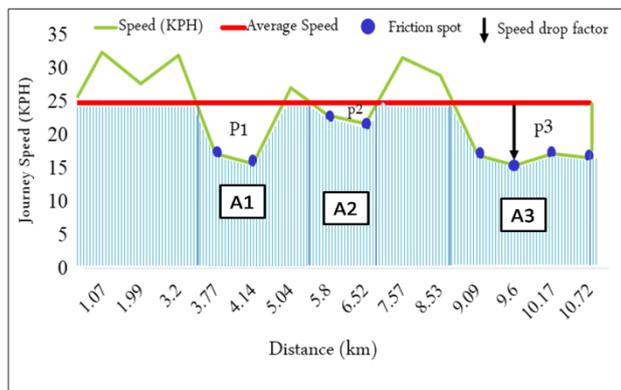
From the speed profile, congested areas of the study corridor have been identified for each peak hour travel. A sample of such speed profile is mentioned below (Fig. 4). From the speed profile curve, friction spots are counted for each travel i.e. the number of times speed falls below the average peak hour speed (red line).

Speed drop factor is considered as the deviation of average speed and actual speed in the congestion stretch along the profile.

The value of TSI has been used to identify the congested nodes i.e. the higher the value of TSI, the higher the level of congestion. The congestion patch areas needed to calculate TSI have been estimated using MATLAB.



**Fig. 3** The Interface of Speedometer GPS App



Source Author's Calculation, 2018

Fig. 4A Sample Speed Profile for the Study Corridor

4.2 Identification of Possible Factors Contributing to Congestion

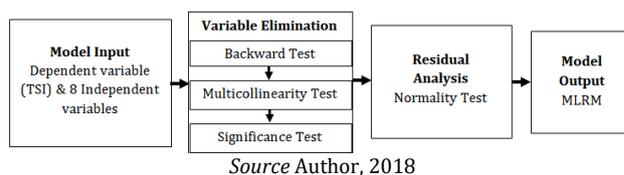
From volume to capacity ratio it is found that in some places congestion has not been found at all. But through speed profile, those locations are found congested at several times. For example, in Doulatpur, V/C ratio is estimated 0.35. There should not be any congestion as the V/C ratio is less than 0.7 (Lindley, 1987). But congestion does exist there as road capacity is not utilized properly due to illegal on-street parking and road side informal businesses. If road capacity can be utilized fully, congestion will not exist in such places even in peak hours.

4.3 Notations used in MLR Model

Dependent variable: TSI = Travel Speed Index

Probable independent variables:

- 1) Volume (PCU/hr) = Volume of the stream per half (5.365 km) of the total road section
- 2) % 2W = Percentage of two wheeler vehicles (i.e. motor cycle, cycle) among the total volume (PCU/hr.) of a section
- 3) % 3W = Percentage of three wheeler vehicles (i.e. rickshaw, Mahindra, auto, CNG) among the total volume (PCU/hr.) of a section
- 4) % 4W = Percentage of four wheeler vehicles (i.e. bus, car) among the total volume (PCU/hr.) of a section
- 5) % CV = Percentage of commercial vehicles (i.e. truck, van) among the total volume (PCU/hr.) of a section
- 6) Dwell Time = Stoppage minutes required for boarding and alighting time of the passengers (minutes)
- 7) Friction Spot = Number of times speed drops from the average speed
- 8) Speed Drop Factor = Difference between average speed and actual speed (KPH)



Source Author, 2018

Fig. 5 MLR model development through RStudio

4.4 Developing MLR Model in RStudio

Linear Regression Model Formulation

A linear regression model has been formulated considering 20 data set of TSI against 8 independent variables. Although R squared value is found suitable (0.62), p-value for each independent variable is greater than 0.05 (at 95% confidence level). So, the second step (Backward test i. e. Correlation test) has been followed to identify independent variables which have significant relationship with the dependent variable (TSI).

Correlation Test

The correlation test has been conducted afterwards. Considering the degrees of freedom, residuals and deviances six independent variables have been removed which are not correlated with congestion (TSI variable). Finally, an ANOVA test has been performed to justify the removal of six independent variables.

Multicollinearity Test

Two independent variables i.e. volume and speed drop factor are remained after the correlation test. Then multicollinearity between these variables has been tested to see the correlation among the independent variables. It is found that TSI has a good relationship with volume and speed drop factor whereas the correlation between volume and speed drop factor is not that significant (Table 5).

Table 5 Multicollinearity test of selected variables

	TSI	Volume (PCU/hr.)	Speed Drop Factor
TSI	1	0.6473814	0.5706702
Volume (PCU/hr.)	0.6473814	1	0.3886283
Speed Drop Factor	0.5706702	0.3886283	1

Source Author's Calculation, 2018

Normality Test

To determine whether the data set used in this model is normally distributed or not, Shapiro-Wilk normality test has been conducted (Table 6). Here, p-value is found 0.3201 which is greater than 0.05, suggesting normal distribution (Lee, et al, 2015).

**Table 6** Shapiro-Wilk Test

W = 0.94673	p-value = 0.3201 > 0.05
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Source Author's Calculation, 2018

4.5 Regression Statistics

Coefficient of Determination

The adjusted R-squared value is 0.4848 which signifies that the variation in TSI is 48.48% explained by volume and speed drop factor. Again, the p- value is less than 0.05. So, the model is a good fit (Table 7).

**Table 7** Regression results for congestion analysis

	Estimate	Std. Error	t value	p-value
(Intercept)	0.0167083	0.0217740	2.740	0.0434
Volume (PCU/hr.)	0.0001826	0.0000651	2.805	0.0122
Speed Drop Factor	0.0019625	0.0009332	2.103	0.0507
Multiple R-squared: 0.539, Adjusted R-squared:0.4848, p-value:0.001384				

Source Author's Calculation, 2018

Variables in the Equation

The equation found is: TSI = 0.0167083 + 0.0001826\* volume (PCU/hr.) + 0.0019625\* speed drop factor. The p-value for intercept, volume and speed drop factor is found less than 0.05 at a confidence interval of 95%. So; the intercept, volume and speed drop factor significantly explain the dependent variable TSI i.e. congestion.

F-test

From the F-distribution table it is found that at a significance level of 0.05 and with a degree of freedom of (df) 17, F critical value is 2.168 and the value of F computed is 9.939. As F computed > F critical, the null hypothesis H<sub>0</sub> is rejected at a significance level of 0.05. It defines that the TSI is dependent on independent variables i.e. volume and speed drop factor.

t-Test

From the t-distribution table it is observed that at a significance level of 0.05, t critical value is 1.740, and the value of | t computed | for dependent and independent variables are 2.74, 2.805 and 2.103 respectively. As | t computed | > t critical, the null hypothesis H<sub>0</sub> for each of the three variables is rejected at a significance level 0.05.

Considering the sign of the estimated coefficients, it can be concluded by saying that both of the independent variables have proper sign. The equation may therefore be used for further congestion studies of the study area.

Model Validation

In this section, MAPE (Mean Absolute Percentage Error) has been used to evaluate the proposed MLR model. It is defined by the following equation where A<sub>t</sub> is the actual value and F<sub>t</sub> is the forecasted value (Lee, et l, 2015).

$$M = \frac{1}{n} \sum_{t=1}^n \left| \frac{A_t - F_t}{A_t} \right| \tag{6}$$

It is estimated that the model accounts for 8.86 % error.

5. Summary of the MLR Model

The final regression model shows a positive correlation between volume (PCU/hr) of the study area and congestion index TSI. In real, congestion of the road section increases while total volume increases. This volume data consists of 3 wheeler, 4 wheeler and 2 wheeler vehicles. So vehicle composition variables have got removed in multicollinearity test. Again, a positive correlation exists between TSI and speed drop factor. It mainly happens due to larger boarding and alighting time of passengers. Doulatpur Bazar, Shibbari Circle, Power House and Ferryghat Circle are found to be the most congested nodes within the study corridor.

6. Overall Findings

- 1) In case of Khulna, two major peak hours exist-one in the morning and another is evening peak. Congestion is acute and more time consuming in evening peak.
- 2) In Shibbari, Ferryghat, Power house & Dakbangla Circle, speed drop phenomenon is less than Doulatpur Bazar.
- 3) In Daulatpur, although the V/C ratio is 0.35. There should not be any congestion as V/C ratio is less than 0.7 (Lindley, 1987). Illegal on-street parking and road side informal businesses are the reasons contributing to this (not utilizing the capacity of road).

Conclusion

The present study portrays the importance of using Travel Speed Index (TSI) in defining traffic congestion of urban heterogeneous traffic. For this work a review of past studies on different congestion measures have been done and their merits and demerits are compared from which Travel Speed Index (TSI) is found to be a convenient congestion measure. From the traffic composition in the selected stretch, it is evident that majority of the vehicles are three wheelers. From the MLR model it is observed that congestion (TSI) can be explained with the term of volume and speed drop factor.

## Limitations

Geometric factors like the radius of curvature of the road and influence of the width of road and surface aren't considered in the MLR model.

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